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**CALCULATED VALUES OF TRANSIENT AND STEADY STATE
PERFORMANCE CHARACTERISTICS OF MAN-CARRYING,
CARGO, AND EXTRACTION PARACHUTES**

EUGENE L. HAAK
RICHARD V. HOVLAND

UNIVERSITY OF MINNESOTA

TECHNICAL REPORT AFFDL-TR-66-103

NOVEMBER 1966

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

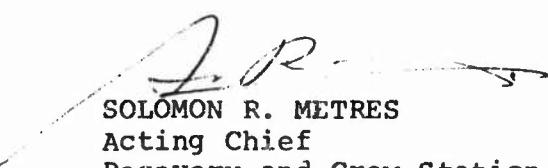
This report was prepared by the Department of Aeronautics and Engineering Mechanics of the University of Minnesota in compliance with U. S. Air Force Contract No. AF 33(615)-2554, "Theoretical Deployable Aerodynamic Decelerator Investigations," Task 606503, "Parachute Aerodynamics and Structures," Project 6065, "Performance and Design of Deployable Aerodynamic Decelerators."

The work accomplished under this contract was sponsored jointly by U. S. Army Natick Laboratory, Department of the Army; Bureau of Aeronautics and Bureau of Ordnance, Department of the Navy; and Air Force Systems Command, Department of the Air Force and was directed by a Tri-Service Steering Committee concerned with Aerodynamic Retardation. The work was administered under the direction of the Recovery and Crew Station Branch, Air Force Flight Dynamics Laboratory, Research and Technology Division. Mr. James H. DeWeese was the project engineer.

This study was guided by Prof. H. G. Heinrich, with Mr. R. J. Niccum and Dr. R. E. Rose contributing significantly to its success. The authors also acknowledge the assistance rendered by students of Aerospace Engineering of the University of Minnesota.

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This technical report was reviewed and is approved.


SOLOMON R. METRES
Acting Chief
Recovery and Crew Station Branch
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ABSTRACT

Opening shocks, snatch forces, opening times, rates of descent, and down times of a number of man-carrying, cargo, and extractor parachutes are calculated on the basis of analytical equations and certain other assumptions. Comparisons of the calculated data with full scale experimental values are somewhat limited, but show reasonable agreement when available. This report represents a first step in an attempt to catalog full scale experimental values from which, eventually, more exact analytical methods can be derived.

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SYMBOLS*

C	effective porosity of canopy (Ref 1)
C_{D_0}	drag coefficient based on canopy surface area, S_0
$(C_{DS})_b$	drag area of suspended load
$(C_{DS})_c$	drag area of uninflated parachute canopy or deployment bag
$(C_{DS})_{max}$	maximum canopy drag area
D_0	nominal canopy diameter, $\sqrt{4 S_0/\pi}$
F_c	average canopy drag force
F_o	opening force of inflating canopy
F_s	snatch force
g	acceleration due to gravity
h	height or altitude
h_l	landing zone elevation
K	dimensionless factor used in determination of opening shock
L_l	length of static line
L_{ex}	length of extraction line
L_R	length of riser
L_r	reefing line length
L_s	length of suspension lines
m_b	mass of suspended load
m_c	mass of parachute canopy
P	tractive force in suspension lines
P'	breaking strength of suspension lines
q_s	impact pressure corresponding to the velocity

* under consideration of definitions of Ref 1

SYMBOLS (CONT.)

S_o	surface area of canopy
T	time ratio, t/t_f
t	time
t_1	time at beginning of deployment (time for static line extension)
t_2	time required for suspension line extension (deployment time)
t_3	time at the end of suspension line stretch or snatch force occurrence
t_{Dt}	time from release to end of suspension line extension
t_f	canopy filling time
t_{fp}	filling time of pilot parachute
t_o	opening time for canopy
t_T	total time from release of parachute to touchdown
$v_{I,1}$	velocity of suspended load at time t_1
$v_{I,2}$	velocity of suspended load at time t_2
$v_{I,3}$	velocity of suspended load at time t_3
$v_{II,1}$	velocity of parachute at time t_1
$v_{II,2}$	velocity of parachute at time t_2
$v_{II,2(\text{rel})}$	velocity of parachute relative to suspended load at time t_2
$v_{II,3}$	velocity of parachute system at time t_3
v_d	deployment velocity
v_e	equilibrium velocity for descent
v_o	launching velocity - aircraft velocity
v_s	velocity at suspension line stretch, snatch velocity
v_T	free fall terminal velocity
w_b	weight of suspended load

SYMBOLS (CONT.)

w_c	weight of canopy only
w_p	weight of complete parachute
Z	number of suspension lines
λ_{total}	total porosity
ξ'	per cent elongation of suspension lines at P'
ξ''	per cent elongation of extraction lines
ρ	air density
ρ_{ave}	average air density between release altitude and landing zone elevation

I. INTRODUCTION

In the following, an attempt has been made to calculate the transient and steady state performance characteristics of several commonly used man-carrying, cargo and extraction parachutes.

The parachutes considered in this report are:

- 1) T-10 personnel parachute
- 2) T-10 reserve parachute
- 3) Two maneuverable parachutes
- 4) T-7A cargo parachute
- 5) G-13 cargo parachute
- 6) G-12D cargo parachute
 - a) with a platform load
 - b) with an A-22 cargo container
- 7) G-11A
- 8) Three standard ringslot extraction parachutes

The physical parameters, deployment systems, simplifying assumptions used in the calculations, governing equations, and results in the form of tables, are presented for each of the above parachutes.

The performance of these parachute systems is considered for an aircraft velocity range between 60 and 150 knots (TAS) at altitudes of 6,500 ft, 11,500 ft, and 20,000 ft (MSL)*.

In this report, all values of aircraft velocity and parachute system velocities as well as the related dynamic pressure are based on true airspeed conditions.

The respective drop zone elevations are 5,000 ft, 10,000 ft, and 18,500 ft, yielding an actual altitude above terrain of 1500 ft. The calculations for the Halo parachute, a free fall deployment, employ somewhat different altitude conditions which are noted where they occur.

The calculations are performed by means of simplifying assumptions and methods which were considered and decided upon in cooperation with members of a Tri-Service Steering Committee and their staffs.

The more important equations and detailed explanations are presented in the Appendix. In many instances, these basic equations have been adjusted slightly to fit the particular parachute system. These variations are noted in the text.

*Mean Sea Level

II. T-10 PERSONNEL PARACHUTE

This is a parachute primarily used by airborne troops. Its principal characteristics are described in Ref 1, while the specific parameters important for this study are listed below.

A. Physical Parameters

Nominal canopy diameter, $D_o = 35 \text{ ft} - 10\% \text{ Flat Extended Skirt Canopy}$

Weight of suspended load, $W_b = 250 \text{ lbs}$

Weight of canopy, $W_c = 11.70 \text{ lbs}$
 $W_p = 14.13 \text{ lbs}$

Canopy material, nylon cloth, MIL-C-7020,
Type I, 1.1 oz/yd² Nominal Porosity=72-132
(Assume 100)

Load Drag Area (C_{DS})_b = 6.0 ft²

Deployment bag drag area, (C_{DS})_c = 1.925 ft²

Bag dimensions: Length, L = 22 in
Width, W = 12 in
Height, H = 5 in

$C_{D_{bag}} = 1.05$ (Ref 2)

Number of suspension lines, Z = 30

Breaking strength of suspension lines,
 $P' = 375 \text{ lbs}$, Type II of spec. MIL-C-5040

Suspension line length, $L_s = 25.5 \text{ ft}$

Static line length, $L_l = 15 \text{ ft}$

Per cent elongation of suspension lines,
 $\xi = 32\%$ at rated breaking strength

Drag coefficient based on D_o , $C_{D_o} = 0.70$

Dimensionless factor, K = 1.3

B. Performance Conditions

In view of the practical use of this parachute, the performance conditions for which the transient and steady state characteristics will be investigated are as follows:

Altitudes:

$$\begin{aligned} h &= 6,500 \text{ ft} \\ h &= 11,500 \text{ ft} \\ h &= 20,000 \text{ ft} \end{aligned}$$

These altitudes are defined as 1500 ft above terrain.

Aircraft Release Velocities:

$$\begin{aligned} V_o &= 60 \text{ knots (TAS)} \\ V_o &= 90 \text{ knots (TAS)} \\ V_o &= 120 \text{ knots (TAS)} \\ V_o &= 150 \text{ knots (TAS)} \end{aligned}$$

These conditions are the same for all parachute studies unless otherwise stated.

C. Deployment System

The T-10 personnel parachute is deployed by a static line one end of which is attached to the aircraft while the free end pulls the deployment bag, in which the parachute is located, off the back pack. Upon extension of the suspension lines, the deployment bag is separated from the parachute and the canopy is free to inflate. The deployment system is presented schematically in Fig 1.

D. Assumptions Used in Calculations

For the velocities, altitudes, and loading conditions, the following simplifications appear to be justified and are used:

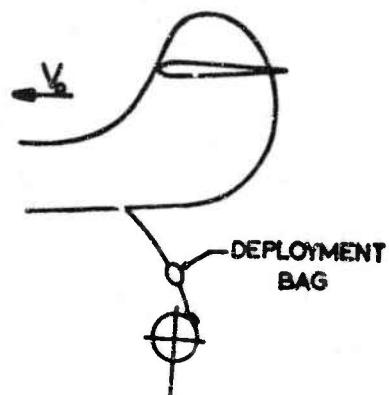
- 1) The snatch force is assumed to be negligible.
- 2) The deployment and canopy filling occur in a near horizontal flight path, and trajectory curvature is neglected.

E. Governing Equations*

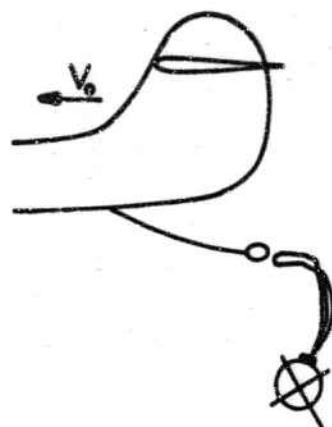
The calculation of the performance characteristics is accomplished in view of the following concepts.

- 1) The total line extension time, t_{Dt} , was calculated, assuming the jumper travels a length of $L_1 + L_s +$

*See Appendix for a summary of equations.



1. Canopy in Deployment Bag



2. Canopy Pulls out of Deployment Bag



3. Suspension Lines Tight



4. Canopy Fully Opened

LEGEND: MAN WITH BACK PACK

Fig. 1 T-10 Personnel Parachute Deployment Sequence

$D_0/2$, acted upon by his own drag and gravity, after leaving the aircraft, by altering Eqn 1 of the Appendix to read:

$$L_1 + L_S + \frac{1}{2}D_0 = \left\{ \left(\frac{gt_{Dt}}{2} \right)^2 + \left[V_0 t_{Dt} - \frac{1}{J_1} \ln \left(1 + J_1 V_0 t_{Dt} \right) \right]^2 \right\}^{\frac{1}{2}} \quad (1a)$$

The terms J_1 , J_c , and J_b are defined in the Appendix. From this equation, the time t_{Dt} was evaluated by an iterative process.

The velocity of the parachutist at this instant is given:

$$V_{I,2} = V_s = \frac{V_0}{J_1 V_0 t_{Dt} + 1} \quad (2a)$$

Since the snatch force is neglected for this type deployment, the main canopy begins to fill at this time. There is a short period of time neglected from when the canopy is first out of the bag in the "sail" shape until it aligns itself along the trajectory. With this time neglected, the term, $V_{I,2}$ is assumed to be the velocity at the beginning of the filling process.

2) The filling time, t_f , for 10% extended skirt canopies was determined in accordance with the method presented in Ref 3, leading to Eqn 3, which was solved* for t_f by means of a computer.

$$D_0 = t_f \int_{T=0}^{T=0.25} \left[\frac{\frac{5.271T^2 + 2.597T + 0.2587}{M}}{\frac{R}{RV_s} + \rho \frac{t_f}{2} \left\{ \frac{S}{N} \left(\frac{M}{N} \ln \frac{M}{R} - T \right) + \frac{PT}{R} \right\}} \right] dT \quad (3)$$

where

$$M = W_{total} + \rho D_0^3 (0.009169T + 0.00006478)$$

$$N = 0.009169 \rho D_0^3$$

$$P = 0.00647 (CDS)_{max} + (CDS)_b$$

$$R = \frac{W_{total}}{g} + 0.0006478 \rho D_0^3$$

$$S = 0.1445 (CDS)_{max}$$

*This and all other computer solutions mentioned in the following were performed at Research and Technology Division, Wright-Patterson Air Force Base, Dayton, Ohio.

V_s = snatch velocity = $V_{I,2}$

ρ = density

t_f = filling time

3) The opening force, F_o , was calculated in accordance with Ref 4, where the maximum force is:

$$F_o = C_{D_0} S_0 \rho q_s \times K \quad (4)$$

and

q_s = impact pressure corresponding to the velocity,

$V_s = V_{I,2}$; and x and K are dimensionless factors for various types of parachutes.

4) The total opening time, t_o , is the sum,

$$t_o = t_{D_t} + t_f \quad (5)$$

5) The rate of descent, or the equilibrium velocity, V_e , was determined from the force equilibrium, expressed as

$$V_e = \frac{2}{D_0} \sqrt{\frac{2W_{\text{total}}}{\pi C_{D_0} \rho_{\text{ave}}}} \quad (6)$$

where ρ_{ave} is the average density between landing zone elevation and release altitude, and W_{total} is the total weight of the parachute and suspended load. This assumes that there is no altitude loss during the opening process. For the large cargo parachutes, however, where t_o is relatively large, this altitude loss may be significant.

6) The total down time, t_T , is given

$$t_T = t_o + \frac{1500}{V_e} \quad (7)$$

F. Results

The results of the performance calculations performed in accordance with the conditions explained above are presented in Table I.

TABLE I
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
T-10 PERSONNEL PARACHUTE

Release Altitude, h = 6,500 ft								Landing Zone Elevation, h ₁ = 5,000 ft							
V _o (knots/ TAS)	V _s (ft/ sec)	V _e (ft/ sec)	t _{Dt} (sec)	Ref. t _{Dt} Exp (sec)	t _f (sec)	Ref. t _f Exp (sec)	t _o (sec)	Ref. t _o Exp (sec)	t _T (sec)	Ref. t _T Exp (sec)	F _s (#)	Ref. F _s Exp (#)	F _o (#)	Ref. F _o Exp (#)	
60	88.6	19.8	1.88		2.50		4.38		80.14					559	
90	125.8	19.8	1.81		1.77		3.58		79.34					1127	
120	161.4	19.8	1.67		1.36		3.03		78.79					1854	
150	196.8	19.8	1.50		1.12		2.62		78.38					2758	
Release Altitude, h = 11,500 ft								Landing Zone Elevation, h ₁ = 10,000 ft							
60	90.2	21.4	1.89		2.37		4.26		74.35					595	
90	128.9	21.4	1.83		1.68		3.51		73.60					1217	
120	165.6	21.4	1.71		1.30		3.01		73.10					2010	
150	201.8	21.4	1.56		1.07		2.63		72.72					2985	
Release Altitude, h = 20,000 ft								Landing Zone Elevation, h ₁ = 18,500 ft							
60	92.7	24.6	1.89		2.30		4.19		65.17					570	
90	133.6	24.6	1.86		1.60		3.46		64.44					1186	
120	172.3	24.6	1.78		1.23		3.01		63.99					1974	
150	210.2	24.6	1.66		1.02		2.63		63.66					2940	

III. T-10 RESERVE PARACHUTE, CHEST PACK

The T-10 reserve parachute is an integral part of the T-10 troop parachute assembly, and the study of its transient and steady state performance characteristics has been accomplished essentially in the same manner as the one used in the preceding chapter, but because it is a canopy - first deployment, the snatch force cannot be neglected. In addition, this canopy is deployed by a pilot parachute, which is described and considered in the calculations.

A. Physical Parameters

1) Main Canopy

$D_o = 24$ ft - circular flat canopy

$W_b = 250$ lbs

$W_c = 5.93$ lbs

$W_p = 8.06$ lbs

Canopy material, nylon cloth, MIL-C-7020
Type I, 1.6 oz/yd² Nominal Porosity = 72-132

$(c_{DS})_b = 6.0$ ft²

Uninflated canopy drag area, $(c_{DS})_c = 2.2$ ft²

$Z = 24$ suspension lines

$P' = 550$ lbs - Type III of Spec. MIL-C-5040

$L_s = 20$ ft

$\xi' = 35\%$ at rated breaking strength

$C_{D_o} = 0.75$

$K = 1.4$

2) Pilot Parachute - AF Drawing 49J 7161

$D_o = 3$ ft Flat octagonal

Material, nylon cloth, MIL-C-7020, Type I
Nominal Porosity = 72-132 ft³/ft²-min.

$Z = 8$

$P' = 100$ lbs - MIL-C-5040B, Type I

$$L_s = 31 \text{ in}$$

$\xi' = 30\%$ at rated breaking strength

$$C_{D_0} = 0.55$$

B. Deployment System

The T-10 personnel reserve parachute is deployed manually by a ripcord. This releases a spring-loaded pilot parachute which extracts the main canopy from the pack, followed by the suspension lines (Fig 2).

C. Assumptions Used in Calculations

The following simplifications are used:

- 1) Although it is realized that this canopy in an emergency use may deploy and open in vertical fall, the calculations of snatch force and filling time utilize the existing equations for a horizontal or near horizontal trajectory.
- 2) The opening shock of the pilot parachute is neglected, and it is assumed that at the time t_{fp} , the pilot parachute is fully open and the deployment of the reserve parachute begins at this instant.
- 3) V_o is considered as the velocity of the system when the reserve parachute ripcord is pulled.

D. Governing Equations

As before, transient and steady state performance characteristics are calculated in view of existing concepts and equations.

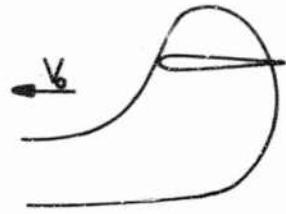
- 1) The pilot parachute filling time, t_{fp} , has been calculated from Ref 7.

$$t_{fp} = \frac{2 D_0}{3 V_o \pi (\frac{9}{70} - \frac{C}{3})} \quad (8)$$

The velocity of this instant is then given by:

$$V_d = V_{I,1} = V_{II,1} = \frac{V_o}{J_1 V_o t_{fp} + 1} \quad (2)$$

and represents the system velocity when the main canopy begins to deploy.



1. Man Out of Aircraft



2. Pack Opened Manually and Pilot Chute Released

LEGEND: MAN WITH CHEST PACK



3. Canopy Extracted by Pilot Chute



4. Canopy Filled

Fig. 2 T-10 Personnel Reserve Chest Pack Deployment Sequence

2) The time for suspension line extension, t_2 , can then be found by iteration of the equation

$$L_s = \frac{1}{J_b} \ln (1 + J_b V_d t_2) - \frac{1}{J_c} \ln (1 + J_c V_d t_2) \quad (9)$$

where the J_c term includes the drag areas of both the inflating canopy and the pilot parachute.

The velocities of the primary and secondary bodies, man and reserve parachutes, respectively, at time t_2 , were determined from:

$$V_{I,2} = \frac{V_d}{J_b V_d t_2 + 1} \quad (10)$$

$$V_{II,2} = \frac{V_d}{J_c V_d t_2 + 1} \quad (11)$$

$$V_{II,2(\text{rel})} = V_{I,2} - V_{II,2} \quad \text{and} \quad (12)$$

$$V_{I,3} = V_{II,3} = V_{I,2} = V_s \quad (13)$$

3) The snatch force was determined from the following equation (Ref 1),

$$F_s = P + F_c \quad (14)$$

where the aerodynamic drag is

$$F_c = \frac{\rho}{2} (C_{DS})_c \frac{V_{II,2}^2 + V_{II,3}^2}{2} \quad (15)$$

and the dynamic force

$$P = \sqrt{\frac{m_c [V_{II,2(\text{rel})}^2]_{ZP}}{L_s \xi'}} \quad (16)$$

4) t_{Dt} is the time from the release to the instant at which the deployment begins, t_{fp} , plus the time for suspension line extension, t_2 .

$$t_{Dt} = t_{fp} + t_2 \quad (17a)$$

5) The filling time, t_f , for circular flat canopies was determined by the method of Ref 2, and a computer solution for t_f was obtained from

$$D_0 = t_f \int_{T=0}^{T=0.3} \left[\frac{1.873T^2 + 2.96T + 0.0886}{\frac{M}{RV_S} + \frac{\rho D_0^3}{2} \left\{ \frac{S}{N} \left(\frac{M}{N} \ln \frac{M}{R} - T \right) + \frac{PT}{R} \right\}} \right] dT \quad (18)$$

with the parameters

$$M = \frac{W_{total}}{g} + \rho D_0^3 (0.020624T + 0.0000264)$$

$$N = 0.020624 \rho D_0^3$$

$$P = 0.003733 (c_{DS})_{max} + (c_{DS})_w$$

$$R = \frac{W_{total}}{g} + 0.0000264 \rho D_0^3$$

$$S = 0.12237 (c_{DS})_{max}$$

6) The opening force, F_o , was calculated by Eqn 4.

7) The opening time, t_o , is the time from release to the time the canopy is fully inflated.

$$t_o = t_{Dt} + t_f \quad (5)$$

8) The rate of descent, V_e , was determined from the equilibrium conditions (Eqn 6) where ρ_{ave} is the average density between release altitude and landing zone elevation.

9) Total down time, t_T , was determined by

$$t_T = t_o + \frac{1500}{V_e} \quad (7)$$

where the release altitude is 1500 ft above ground.

E. Results

The results of the performance calculations are presented in Table II.

TABLE II
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
T-10 PERSONNEL RESERVE PARACHUTE

Release Altitude, $h = 6,500$ ft								Landing Zone Elevation, $h_1 = 5,000$ ft							
V_o (knots/ TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{Dt} (sec)	Ref. t_{Dexp} (sec)	t_f (sec)	Ref. t_{fexp} (sec)	t_o (sec)	Ref. t_{oexp} (sec)	t_T (sec)	Ref. t_{Texp} (sec)	F_s (#)	Ref. F_{sexp} (#)	F_o (#)	Ref. F_{oexp} (#)	
60	94.5	26.5	0.942		1.54		2.480		59.08		827		721		
90	141.8	26.5	0.648		1.03		1.655		58.26		1249		1620		
120	189.1	26.5	0.471		0.77		1.241		57.85		1679		2881		
150	236.4	26.5	0.377		0.62		0.993		57.60		2115		4501		
Release Altitude, $h = 11,500$ ft								Landing Zone Elevation, $h_1 = 10,000$ ft							
60	95.2	27.4	0.995		1.53		2.525		57.27		785		685		
90	142.7	27.4	0.663		1.02		1.684		56.43		1186		1541		
120	190.3	27.4	0.498		0.77		1.263		56.01		1593		2740		
150	237.9	27.4	0.398		0.61		1.010		55.76		2006		4280		
Release Altitude, $h = 20,000$ ft								Landing Zone Elevation, $h_1 = 18,500$ ft							
60	96.1	28.9	1.108		1.52		2.624		54.53		716		670		
90	144.1	28.9	0.99		1.01		1.750		53.65		1081		1507		
120	192.1	28.9	0.544		0.76		1.312		53.22		1450		2679		
150	240.2	28.9	0.443		0.61		1.050		52.95		1824		4186		

IV. MANEUVERABLE PERSONNEL PARACHUTE

With the advancement of parachute technology, maneuverable parachutes have come into existence which, from the standpoint of aerodynamics, are highly interesting aerodynamic vehicles. The following studies, however, are merely concerned with the transient and steady state conditions similar to those considered in the preceding sections. Under investigation here is a modified T-10 troop type parachute.

A. Physical Parameters

$D_0 = 35 \text{ ft} - 10\% \text{ flat extended skirt canopy with cut-out in rear, static line deployment}$

$W_b = 250 \text{ lbs}$

$W_c = 11.87 \text{ lbs}$

$W_p = 14.3 \text{ lbs}$

Canopy Material, nylon cloth, MIL-C-7020 Type I,
1.1 oz/yd²

$(c_{DS})_b = 6.0 \text{ ft}^2$

$(c_{DS})_c = 1.925 \text{ ft}^2 \text{ (deployment bag)}$

Bag dimensions: Length, L = 22 in
Width, W = 12 in
Height, H = 5 in

$c_{D_{bag}} = 1.05 \text{ (Ref 2)}$

Z = 30 suspension lines

$P' = 375 \text{ lbs} - \text{Type II of Spec. MIL-C-5040}$

$L_s = 25.5 \text{ ft}$

$L_1 = 15 \text{ ft}$

$\xi' = 32\% \text{ at rated breaking strength}$

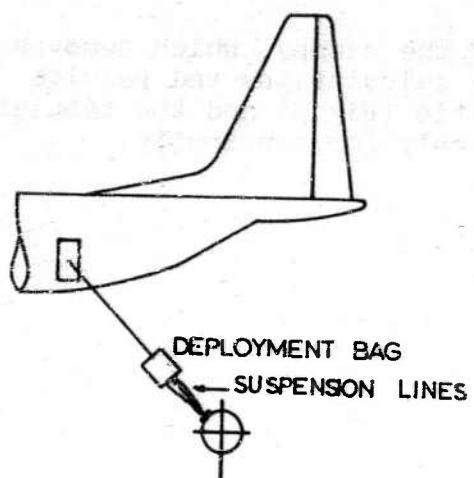
$c_{D_0} = 0.70$

$K = 1.3$

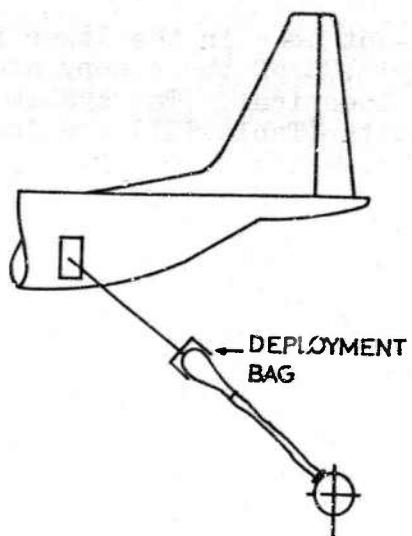
B. Deployment System

Since this system is identical to the T-10 main canopy described in Section II, with the exception of a

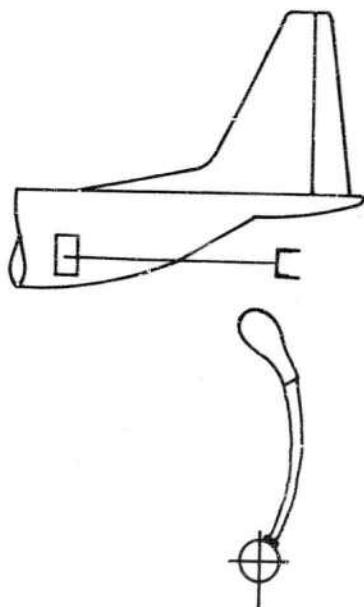
cut-out area in the lower rear of the canopy, which removes only 3.7% of the canopy area, all calculations and results are identical. The system schematic (Fig 3) and the tabulated results (Table III) are included only for continuity.



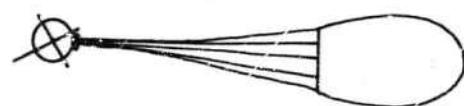
1. Canopy in Deployment Bag



2. Static Line Tight



3. Canopy Alignment With
Trajectory Angle



4. Suspension Lines Tight



5. Canopy Fully Open

LEGEND: MAN WITH
BACK PACK

Fig 3. Maneuverable Personnel Parachute Deployment Sequence

TABLE III
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
MANEUVERABLE PERSONNEL PARACHUTE

Release Altitude, $h = 6,500$ ft								Landing Zone Elevation, $h_1 = 5,000$ ft							
V_o (knots) (TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{D_t} (sec)	Ref. $t_{D_{exp}}$ (sec)	t_f (sec)	Ref. t_f^{exp} (sec)	t_o (sec)	Ref. $t_{o_{exp}}$ (sec)	t_T (sec)	Ref. $t_{T_{exp}}$ (sec)	F_s (#)	Ref. $F_{s_{exp}}$ (#)	F_o (#)	Ref. $F_{o_{exp}}$ (#)	
60	88.6	19.8	1.88	2.50		4.38		80.14							
90	125.8	19.8	1.81		1.77		3.58		79.34				559		
120	161.4	19.8	1.67		1.36		3.03		78.79				1127		
150	196.2	19.8	1.50		1.12		2.62		78.38				1854		
Release Altitude, $h = 11,500$ ft															
60	90.2	21.4	1.89		2.37		4.26		74.35						
90	128.9	21.4	1.83		1.68		3.51		73.60				596		
120	165.6	21.4	1.71		1.30		3.01		73.10				1217		
150	201.5	21.4	1.56		1.07		2.63		72.72				2010		
Release Altitude, $h = 20,000$ ft															
60	92.7	24.6	1.89		2.30		4.19		65.17						
90	133.6	24.6	1.86		1.60		3.46		64.44				570		
120	172.3	24.6	1.78		1.23		3.01		63.99				1186		
150	210.2	24.6	1.66		1.02		2.69		63.66				1974		
															2940

V. HALO PARACHUTE

The Halo Parachute is the maneuverable parachute of IV above which, however, is deployed in free fall. Its characteristics are identified below.

A. Physical Parameters

1) Main Canopy

$D_0 = 35 \text{ ft} - 10\% \text{ flat extended skirt canopy}$
with cutout in rear

$W_b = 250 \text{ lbs}$

$W_c = 12.17 \text{ lbs}$

$W_p = 14.6 \text{ lbs}$

Canopy Material, Same as IV.

$(C_{DS})_b = 6.0 \text{ ft}^2$

$(C_{DS})_c = 4.69 \text{ ft}^2$ (uninflated canopy)

$Z = 30$ suspension lines

$P' = 375 \text{ lbs} - \text{Type II of Spec. MIL-C-5040}$

$L_s = 25.5 \text{ ft}$

$\xi' = 32\%$ at rated breaking strength

$C_{D0} = 0.70$

$K = 1.3$

2) Pilot Parachute - USAF Drawing 60J 4219

$D_0 \approx 40 \text{ in} - 8 \text{ gore vane type}$

B. Performance Characteristics

Since this is a free fall system, the transient and steady state characteristics shall be considered for the following conditions:

Aircraft Release Altitude:

$h = 11,000 \text{ ft}$

$h = 16,000 \text{ ft}$

$h = 21,000 \text{ ft}$

Parachute Opening Altitude:

$$\begin{aligned} h &= 9,000 \text{ ft} \\ h &= 14,000 \text{ ft} \\ h &= 19,000 \text{ ft} \end{aligned}$$

Terminal Velocity of Parachutist at Altitudes defined above with $(c_{DS})_b \approx 6.0 \text{ ft}^2$ (Ref 5):

$$\begin{aligned} V_T &= 125 \text{ ft/sec} \\ V_T &= 133.8 \text{ ft/sec} \\ V_T &= 155.4 \text{ ft/sec} \end{aligned}$$

C. Deployment System

The parachutist free falls to a preselected altitude above ground (4,000 ft). At this altitude an automatic device, or the man, pulls the ripcord on the main parachute pack and releases the pilot chute. The pilot chute extends the main canopy, the lower portion of which is retained in a quarter bag*. The suspension lines which are stowed on top of the quarter bag, are then extended. The canopy is then released from the quarter bag and inflates (Fig 4).

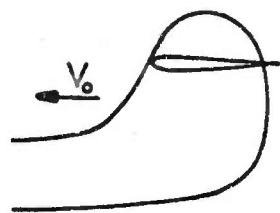
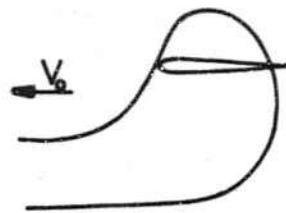
D. Assumptions Used in Calculations

- 1) Although it is realized that this canopy in normal use may deploy and open in vertical fall, the calculations of snatch force and filling time utilize the existing equations for a horizontal or near horizontal trajectory.
- 2) The parachutist was assumed to be at terminal velocity when the ripcord was pulled. To make this approximation valid, a free fall of about 2000 feet was required (Ref 5). For this reason, the aircraft release altitude of 6000 feet above terrain was selected.
- 3) The quarter bag does not effect the deployment and opening characteristics, as defined by the governing equations.

E. Governing Equations

- 1) The parachutist's terminal velocity was calculated from the information given in Ref 5.

*Ref 1



1. MAN OUT OF AIRCRAFT

2. PILOT PARACHUTE DEPLOYED AUTOMATICALLY AT PRESELECTED ALTITUDE



3. PILOT CHUTE EXTRACTS MAIN CANOPY

4. CANOPY FILLED

LEGEND: MAN WITH BACK PACK

Fig. 4 Halo Free Fall Personnel Parachute Deployment Sequence

$$v_T = \frac{\text{altitude lost from exit to terminal velocity}}{\text{time to reach terminal velocity}}$$

where the altitude lost between exit from the aircraft and where terminal velocity is reached was found from a graph (Ref 5) of jump altitude versus altitude lost from exit to terminal vertical velocity. Also from Ref 5, it was possible to determine the time it takes the jumper to reach terminal vertical velocity after he has left the aircraft.

2) The deployment time for the pilot parachute has been neglected. However, the filling time has been calculated from Eqn 8.

3) The deployment velocity of the canopy was then calculated from Eqn 2.

4) The time for suspension line extension was calculated by the iteration process of Eqn 9.

5) The remaining calculations proceeded exactly as those shown in Section III, but utilizing the parameters characteristic of the extended skirt parachute. It should be pointed out, however, that although a snatch force was calculated it may be a considerably higher value than that experienced in actuality with a quarter bag deployment.

F. Results

The results of these calculations are presented in Table IV.

TABLE IV
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
HALO PERSONNEL PARACHUTE - FREE FALL VERSION

Release Altitude, $h = 9,000$ ft								Landing Zone Elevation, $h_1 = 5,000$ ft							
v_o (ft/ sec)	v_s (ft/ sec)	v_e (ft/ sec)	t_{D_t} (sec)	Ref. $t_{D_{exp}}$ (sec)	t_f (sec)	Ref. $t_{f_{exp}}$ (sec)	t_o (sec)	Ref. $t_{o_{exp}}$ (sec)	t_{T_l} (sec)	Ref. $t_{T_{exp}}$ (sec)	F_s (#)	Ref. $F_{s_{exp}}$ (#)	F_o (#)	Ref. $F_{o_{exp}}$ (#)	
125	116.4	20.2	.79		1.96		2.75		209.77		1328		934		
Release Altitude, $h = 14,000$ ft								Landing Zone Elevation, $h_1 = 10,000$ ft							
134	125.5	21.8	.79		1.79		2.58		186.07		1366		1087		
Release Altitude, $h = 19,000$ ft								Landing Zone Elevation, $h_1 = 15,000$ ft							
155	146.2	23.7	.72		1.51		2.23		171.27		1498		1323		

VI. T-7A CARGO PARACHUTE

As a static line deployed cargo parachute for light loads, its important parameters are:

A. Physical Parameters

$D_O = 28 \text{ ft}$ - circular flat canopy

$W_b = 500 \text{ lbs}$

$W_c = 12.62 \text{ lbs}$

$W_p = 15.46 \text{ lbs}$

Canopy Material, nylon cloth, MIL-C-7020, Type II,
1.6 oz/yd² Nominal Porosity = 90-176

$(c_{DS})_b = 7.125 \text{ ft}^2$

A-21 cargo container dimensions:

Length, $L = 30 \text{ in}$
Width, $W = 30 \text{ in}$
Height, $H = 20 \text{ in}$

$c_{DA-21} = 1.14$ (Ref 2)

$(c_{DS})_c = 3 \text{ ft}^2$ (uninflated canopy)

$Z = 28$ suspension lines

$P' = 550 \text{ lbs}$ - Type III of Spec. MIL-C-5040

$L_s = 22 \text{ ft}, 10 \text{ in}$

$L_l = 15.5 \text{ ft}$

$\xi' = 35\%$ at rated breaking strength

$c_{D_O} = 0.75$

$K = 1.4$

B. Deployment System

The parachute-load system is released in such a manner that the parachute canopy is deployed first, followed by the suspension lines. The deployment is accomplished by a static line attached to the aircraft. Upon full extension of the suspension lines, the skirt hesitator* tie is broken

*Ref 1

and the tie between the canopy and the static line is also separated (Fig 5).

C. Assumptions Used in Calculations

- 1) The deployment and opening sequence was assumed to take place in a near horizontal condition.
- 2) The snatch force is negligible compared to the opening force for the static line deployment.
- 3) Effects of the skirt hesitator were not considered.

D. Governing Equations

With these assumptions, the following equations can be used.

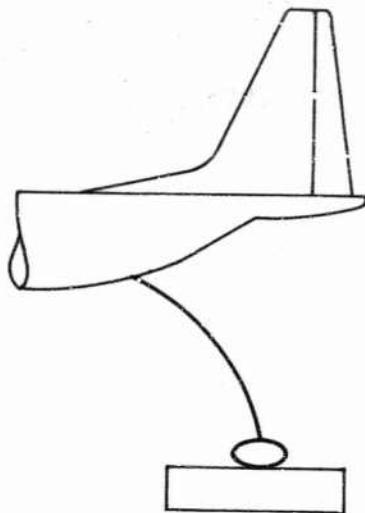
- 1) The time, t_1 , for static line extension is found by means of an iteration of the Eqn 1:

$$L_1 = \left\{ \left(\frac{gt_1}{2} \right)^2 + \left[v_o t_1 - \frac{1}{J_1} \ln (1 + J_1 v_o t_1) \right]^2 \right\}^{\frac{1}{2}} \quad (1)$$

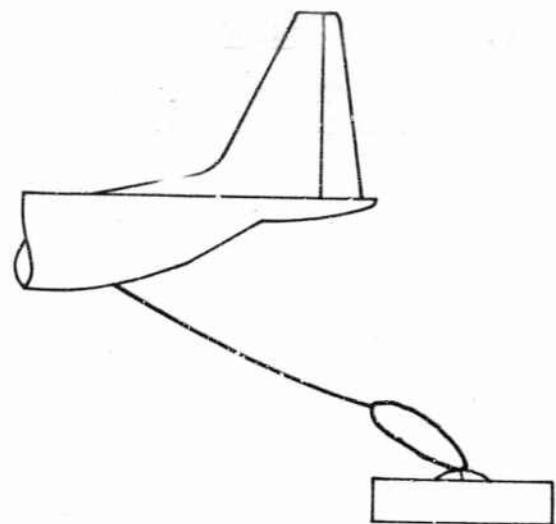
The time, t_1 , is then used to determine the velocity at the instant of static line extension, V_d , from Eqn 2.

- 2) Time, t_2 , for suspension line extension can be found by an iterative solution of Eqn 9, and the related velocity $V_{I,2} = V_s$ was calculated from Eqn 10.

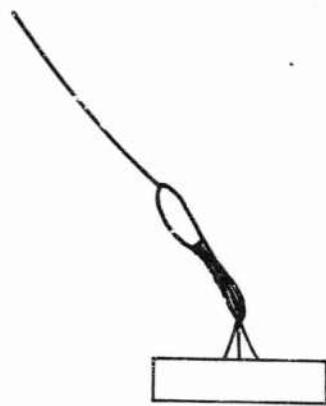
- 3) The time, t_{Dt} , was found from Eqn 17.
- 4) The filling time, t_f , of the T-7A cargo parachute was determined by the method of Ref 3 and the related computer solution for t_f was obtained from Eqn 18.
- 5) The opening force, F_o , was calculated from Eqn 4.
- 6) The opening time, t_o , was found from Eqn 5.
- 7) The rate of descent, v_e , was determined from the equilibrium condition (Eqn 6).
- 8) Total down time, t_T , was determined from Eqn 7.



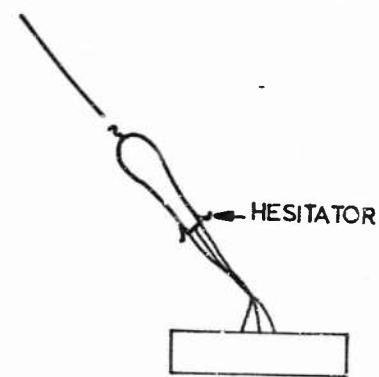
1. Cargo Out of Aircraft



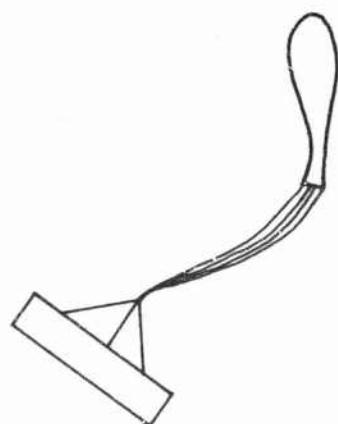
2. Canopy and Suspension Lines Pulled From Pack by Static Line



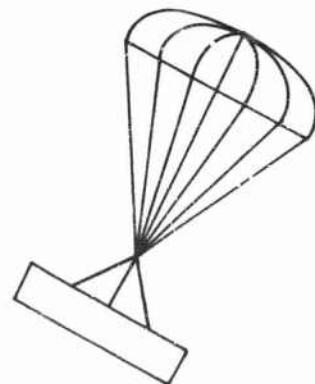
3. Suspension Lines Tight



4. Canopy Free to Open



5. Canopy Alignment With Trajectory Angle



6. Canopy Filled

Fig 5. T-7A Cargo Parachute Deployment Sequence

E.

Results

The results of the performance calculations are presented in Table V.

TABLE V
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
T-7A CARGO PARACHUTE

Release Altitude, $h = 6,500$ ft							Landing Zone Elevation, $h_1 = 5,000$ ft							
V_o (knots/ TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{D_t} (sec)	Ref. t_{Dexp} (sec)	t_f (sec)	Ref. t_{fexp} (sec)	t_o (sec)	Ref. t_{oexp} (sec)	t_T (sec)	Ref. t_{Texp} (sec)	F_s (#)	Ref. F_{sexp} (#)	F_o (#)	Ref. F_{oexp} (#)
60	92.5	31.4	2.12		1.84		3.96		4.842				894	
90	136.2	31.4	1.71		1.25		2.96		47.42				1939	
120	178.5	31.4	1.50		0.95		2.45		46.91				3331	
150	219.9	31.4	1.35		0.77		2.12		46.58				5054	
Release Altitude, $h = 11,500$ ft							Landing Zone Elevation, $h_1 = 10,000$ ft							
60	93.5	33.2	2.18		1.82		4.00		45.11				816	
90	137.9	33.2	1.78		1.23		3.01		44.12				1782	
120	181.2	33.2	1.55		0.94		2.49		43.60				3062	
150	223.4	33.2	1.40		0.76		2.16		43.27				4657	
Release Altitude, $h = 20,000$ ft							Landing Zone Elevation, $h_1 = 18,500$ ft							
60	95.0	35.0	2.27		1.79		4.06		39.81				749	
90	140.0	35.0	1.86		1.21		3.07		38.82				1638	
120	185.3	35.0	1.63		0.90		2.53		38.28				2844	
150	228.7	35.0	1.50		0.74		2.24		37.99				4332	

VII. G-13 CARGO PARACHUTE

The cargo parachute type G-13 is a static line deployed hemispherical parachute for light loads. Its important parameters are listed below.

A. Physical Parameters

$D_0 = 32 \text{ ft}$ - hemispherical canopy

$W_b = 500 \text{ lbs}$

$W_c = 23.89 \text{ lbs}$

$W_p = 33.89 \text{ lbs}$

$(C_{DS})_b = 7.125 \text{ ft}^2$

A-21 cargo container dimensions:

Length, $L = 30 \text{ in}$

Width, $W = 30 \text{ in}$

Height, $H = 20 \text{ in}$

$C_{DA-21} = 1.14$ (Ref 2)

$(C_{DS})_c = 3.92 \text{ ft}^2$ (uninflated canopy)

Canopy Material, cotton muslin, 4.25 oz/yd^2 ,
MIL-C-4279 Type II Nominal Porosity = $153-253 \text{ ft}^3/\text{ft}^2\text{-min}$

$Z = 20$ suspension lines

$P' = 400 \text{ lbs}$ - Type I of Spec. MIL-C-4232

$L_s = 30 \text{ ft}$

$L_l = 15 \text{ ft}$

$\xi' = 12\%$ at rated breaking strength

$C_{D_0} = 0.75$

$K = 1.3$

B. Deployment System

The deployment system is exactly like the one described in the preceding section related to the T-7A parachute (Fig 6).

C. Assumptions Used in Calculations

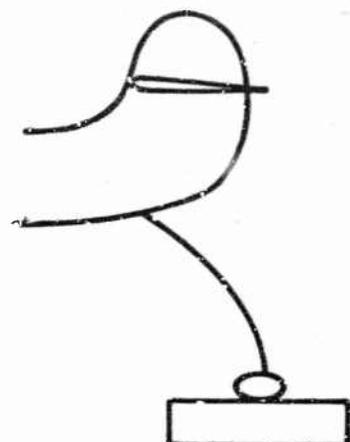
- 1) The deployment and opening sequence was assumed to take place in a near horizontal condition.
- 2) The snatch force was negligible compared to the opening force for the static line deployment.
- 3) Effects of the skirt hesitator were not considered.
- 4) The extended skirt equations were used in the filling time calculation.

D. Governing Equations

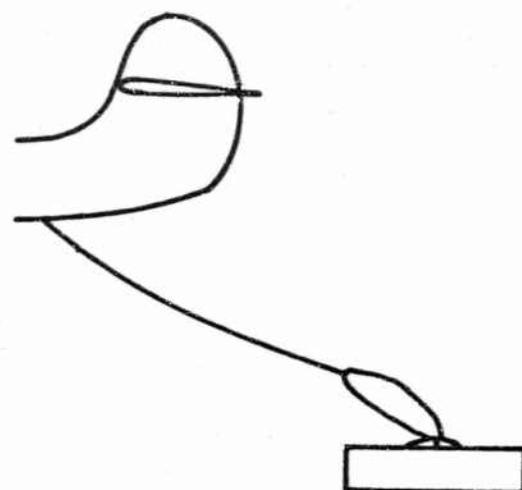
- 1) The time, t_1 , for static line extension is determined from an iteration of Eqn 1. This time is then used to determine the velocity at the instant of static line extension, V_d , from Eqn 2. The time, t_2 , for suspension line extension can then be found by a trial and error solution of Eqn 9. Finally, the velocity of the system at the beginning of the filling process, V_s , was determined from Eqn 10.
- 2) The deployment time, t_{Dt} , was found from Eqn 17.
- 3) The filling time, t_f , was determined by the method of Ref 3, and in view of assumption 4, the related computer solution for t_f was obtained from Eqn 3.
- 4) The opening force, F_o , was calculated from Eqn 4.
- 5) The opening time, t_o , was found from Eqn 5.
- 6) The rate of descent, V_e , was determined from the equilibrium conditions (Eqn 6).
- 7) The total down time, t_T , was determined from Eqn 7.

E. Results

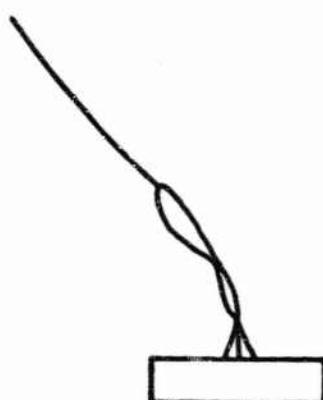
The results of the performance calculations are presented in Table VI.



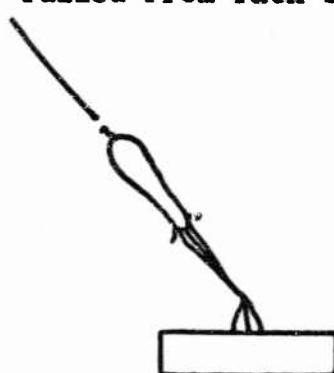
1. Cargo Out of Aircraft



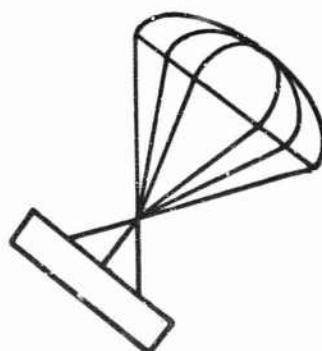
2. Canopy and Suspension Lines Pulled From Pack by Static Line



3. Suspension Lines Tight



4. Canopy Free to Open



5. Canopy Filled

Fig. 6 G-13 Cargo Parachute Deployment Sequence

TABLE VI
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
G-13 CARGO PARACHUTE

Release Altitude, $h = 6,500$ ft								Landing Zone Elevation, $h_1 = 5,000$ ft								
V_o (knots/ TAS)	V_s	V_e (ft/ sec)	t_{D_t}	Ref. $t_{D_t}^{exp}$	t_f	Ref. t_f^{exp}	t_o	Ref. t_o^{exp}	t_T	Ref. t_T^{exp}	F_s	Ref. F_s^{exp}	F_o	Ref. F_o^{exp}	$(\#)$	$(\#)$
60	90.4	29.0	2.75	2.15	4.90	54.05									1083	
90	133.0	29.0	2.15	1.46	3.61	52.76									2359	
120	174.4	29.0	1.83	1.11	2.94	52.09									4029	
150	215.4	29.0	1.59	0.90	2.49	51.60									6146	
Release Altitude, $h = 11,500$ ft								Landing Zone Elevation, $h_1 = 10,000$ ft								
60	91.7	30.0	2.76	2.12	4.88	50.26									294	
90	135.2	35.0	2.16	1.44	3.60	48.98									2158	
120	177.8	30.0	1.86	1.09	2.95	48.36									3739	
150	220.3	30.0	1.60	0.88	2.48	47.86									5731	
Release Altitude, $h = 20,000$ ft								Landing Zone Elevation, $h_1 = 18,500$ ft								
60	93.4	31.7	2.95	2.08	5.03	44.53									909	
90	138.1	31.7	2.30	1.44	3.71	43.21									1987	
120	182.7	31.7	1.92	1.06	2.98	42.48									3479	
150	226.0	31.7	1.71	0.86	2.57	42.07									5325	

VIII. G-12D CARGO PARACHUTE (PLATFORM LOAD)

When the G-12D cargo parachute is used in connection with cargo platforms, its principal parameters are as follows:

A. Physical Parameters

$D_0 = 64$ ft - circular flat canopy

$W_b = 2,200$ lbs

$W_c = 76.79$ lbs

$W_p = 109.5$ lbs (inc. wt. of risers - 4.75 lbs)

$(C_{DS})_b = 76.8 \text{ ft}^2$

Platform dimensions: $L = 8$ ft, $W = 8$ ft

$C_{D_{platform}} = 1.2$ (Ref 2)

$(C_{DS})_c = 7.146 \text{ ft}^2$ (deployment bag)

Bag dimensions:

Length, $L = 40$ in

Width, $W = 24.5$ in

Height, $H = 15$ in

$C_{D_{bag}} = 1.05$ (Ref 2)

Canopy Material, nylon, 2.25 oz/yd², MIL-C-7350
Type I Nominal Porosity = 90-165 ft³/ft²-min

$Z = 64$ suspension lines

$P' = 1,000$ lbs - Type IV of Spec. MIL-C-7515

$L_s = 51$ ft

$\xi' = 20\%$ at rated breaking strength

$L_R = 5$ ft, 5 in - Type X, Class R - MIL-W-27265

$\xi'_{riser} = 28\%$ at rated breaking strength

$C_{D_0} = 0.75$

$K = 1.4$

B. Deployment System

The G-12D parachute with a platform load is extracted from the aircraft by a standard 15 ft extraction parachute, reefed with a 260 in. reefing line. (See Section XI) As the cargo platform leaves the aircraft ramp the extraction force is transferred from the platform to the deployment bag of the main canopy, thus initiating a suspension lines first deployment sequence (Fig 7).

C. Assumptions Used in Calculations

1) The initial velocity, V_0 , is assumed to be the velocity of the platform as it leaves the aircraft, and not the aircraft velocity. This is a necessary assumption since the platform velocity relative to the aircraft varies considerably with operating conditions.

2) The release time, $t = 0$, is assumed to be when the platform leaves the aircraft ramp. The elapsed time for the extraction parachute opening sequence has been calculated in Section XI and can be included as an additive term prior to cargo exit from the aircraft. In addition to this, the time necessary for the cargo to traverse the distance inside the aircraft, under the influence of the extraction parachute drag, must be considered.

3) The deployment and opening sequence was assumed to take place in a near horizontal parachute attitude.

D. Governing Equations

1) The suspension line extension time, t_2 , was determined from Eqn 9 and since there is no static line, $t_1 = 0$. Therefore:

$$t_{Dt} = t_2$$

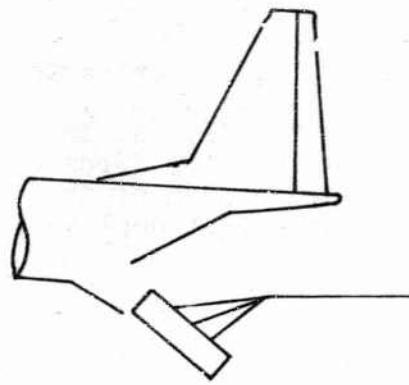
The drag area--mass ratio terms of Eqn 9 are:

J_b - based on platform characteristics

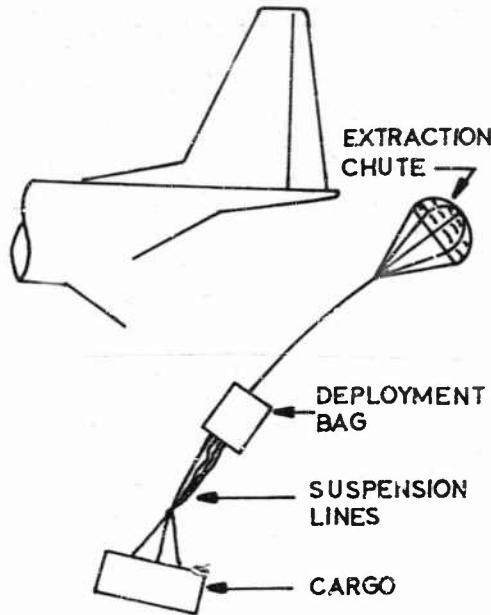
J_c - the sum of the G-12D deployment bag and extraction parachute characteristics

2) The velocities of the platform and parachute required for snatch force calculations were determined from Eqns 10 through 13.

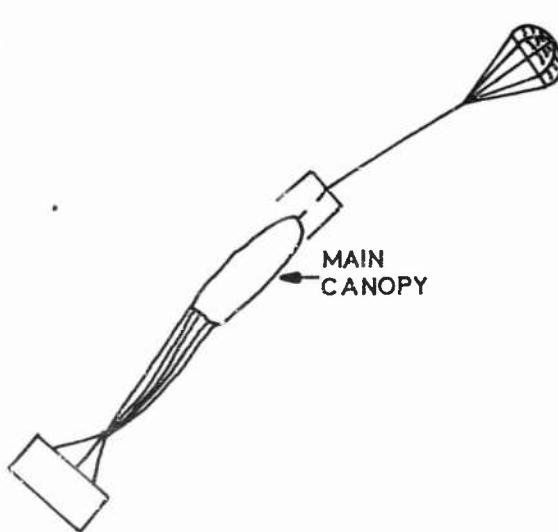
3) The snatch force was calculated from Eqns 14, 15, and 16.



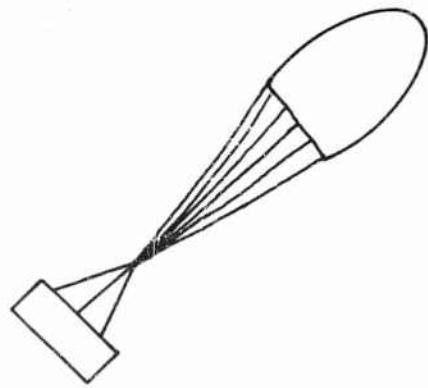
1. Extraction Parachute Force
Transferred to Bridle of
G-12D Parachute Assembly



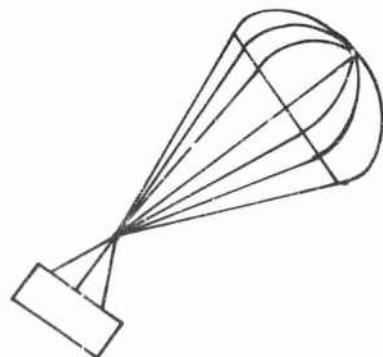
2. Suspension Line
Deployment



3. Line-Stretch: Canopy
is Extracted from
Deployment Bag



4. Canopy Begins to Fill



5. Canopy Filled

Fig 7. G-12D Cargo Parachute Deployment Sequence - Plat-
form Load

4) The filling time, t_f , was determined by the method of Ref 3 and a computer solution for t_f was obtained from Eqn 18.

5) The opening force was found from Eqn 4.

6) The rate of descent, V_e , was determined from the equilibrium condition (Eqn 6).

7) The total down time, t_T , has been calculated from Eqn 7, but it should be viewed with some doubt since the altitude loss during opening may be significant.

E. Results

The results of the performance calculations are presented in Table VII.

TABLE VII
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
G-12D CARGO PARACHUTE - PLATFORM LOAD

Release Altitude, $h = 6,500$ ft								Landing Zone Elevation, $h_1 = 5,000$ ft								
V_o (knots/ TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{D_L} (sec)	Ref. t_{DExp}	t_f (sec)	Ref. t_{fExp}	t_o (sec)	Ref. t_{oExp}	t_T (sec)	Ref. t_{TExp}	F_s	Ref. F_{sExp}	F_o	Ref. F_{oExp}	F_o	Ref. F_{oExp}
60	90.3	30.9	1.15		4.63		5.78		54.32		8.042				2,908	
90	135.6	30.9	.76		3.07		3.83		52.37		12.070				6,555	
120	180.8	30.9	.57		2.32		2.89		51.43		16.123				11,654	
150	225.8	30.9	.46		1.95		2.41		50.95		20.213				17,820	
Release Altitude, $h = 11,500$ ft								Landing Zone Elevation, $h_1 = 10,000$ ft								
60	91.5	33.4	1.20		4.47		5.67		50.58		7,904				2,892	
90	137.2	33.4	.80		2.98		3.78		48.69		11,820				6,453	
120	182.8	33.4	.60		2.24		2.84		47.75		15,845				11,455	
150	228.5	33.4	.48		1.91		2.39		47.30		19,841				17,250	
Release Altitude, $h = 20,000$ ft								Landing Zone Elevation, $h_1 = 18,500$ ft								
60	93.1	38.4	1.29		4.28		5.57		44.63		7,698				2,694	
90	139.7	38.4	.86		2.84		3.70		42.76		11,378				6,090	
120	186.3	38.4	.64		2.08		2.72		41.78		15,168				10,981	
150	232.6	38.4	.52		1.83		2.35		41.41		13,050				16,050	

IX. G-12D CARGO PARACHUTE (A-22 Container)

The G-12D cargo parachute is also used in connection with the A-22 cargo container. In this combination the performance characteristics of the parachute are slightly different from those observed with the platform, as presented in the preceding section. The typical parameters are:

A. Physical Parameters

1) Main Canopy

$D_0 = 64$ ft - circular flat canopy

$W_b = 2,200$ lbs

$W_c = 76.79$ lbs

$W_p = 109.5$ lbs (including risers)

Canopy Material, nylon cloth, MIL-C-7850,
Type I, 2.25 oz/yd² Nominal Porosity =
90-165 ft³/ft²-min

$(C_{DS})_b = 16.31$ ft²

A-22 container dimensions:

Length, L = 52 in

Width, W = 43 in

Height, H = 50 in

$C_{DA-22} = 1.05$ (Ref 6)

$(C_{DS})_c = 7.146$ ft² (deployment bag)

Bag dimensions:

Length, L = 40 in

Width, W = 24.5 in

Height, H = 15 in

$C_{D_{bag}} = 1.05$ (Ref 2)

Z = 64 suspension lines

P' = 1,000 lbs - Type IV of Spec. MIL-C-7515

$L_s = 51$ ft

$L_l = 15$ ft

ξ' = 20% at rated breaking strength

L_R = 5 ft, 5 in - Type X, Class R - MIL-W-27265

ξ'_r = 28% at rated breaking strength

C_{D_0} = 0.75

K = 1.4

2) Pilot Parachute - Drawing No. 53E 6803

D_0 = 5.66 ft - octagonal canopy

Z = 8

L_S = 5.5 ft - MIL-C-7515 Type II

L_1 = 15 ft

L_R = 9.25 ft

C_{D_0} = 0.75

B. Deployment System

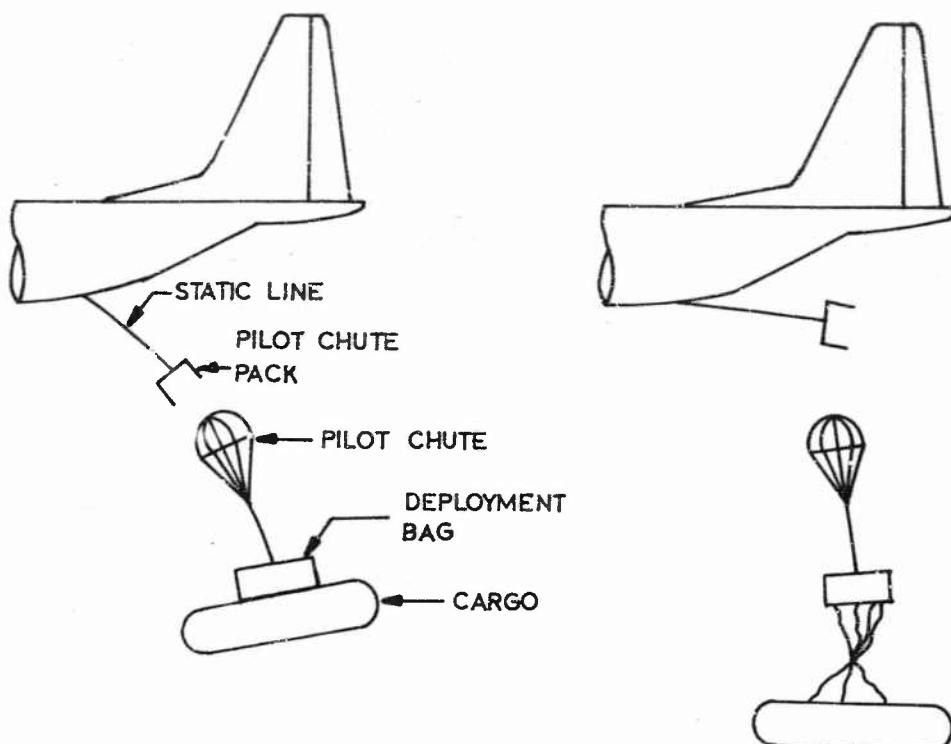
After the parachute-load assembly is released from the aircraft, the pilot chute is deployed from its pack by a static line. The pilot parachute extracts first the suspension lines of the main parachute from its deployment bag and then the main canopy. The deployment bag is then separated and the canopy is free to inflate (Fig 8).

C. Assumptions Used in Calculations

- 1) The calculations are limited to the cases of near horizontal deployment.
- 2) The pilot parachute filling time has been neglected.

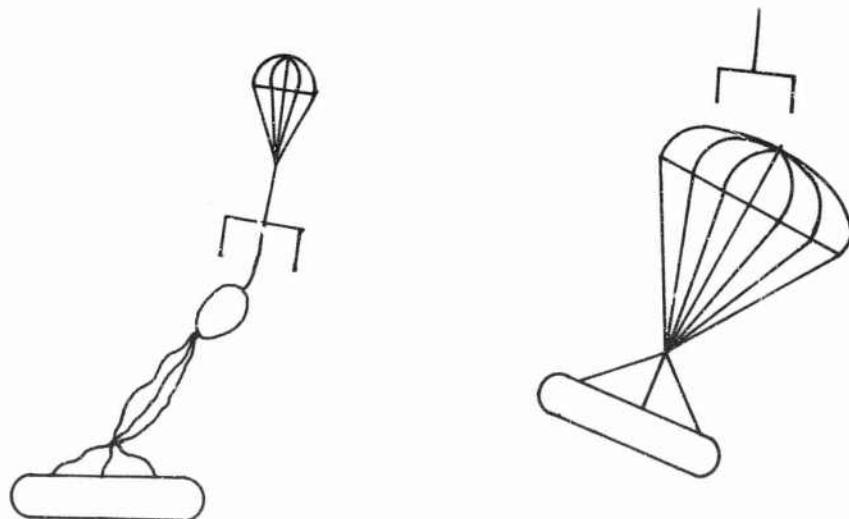
D. Governing Equations

- 1) The cargo is assumed to free fall, acted upon only by its own weight and drag while the static line and pilot parachute are deployed. The time for this occurrence is obtained from a modified form of Eqn 1 of the Appendix, where the length L_1 is the sum of the static line length (15 ft), the pilot chute suspension line length (5.5 ft), and the pilot parachute riser length (9.25 ft). The J_c term is



1. Pilot Chute Deployed

2. Suspension Lines Out



3. Main Canopy Out

4. Canopy Opens and Separates From Deployment Bag

Fig 8. G-12D Cargo Parachute Deployment Sequence - A-22 Cargo Container

the sum of the G-12D deployment bag and the pilot parachute characteristics.

2) The deployment velocity of the main canopy is determined from Eqn 2, using the time calculated in 1) above, and neglects the small velocity change and time increment during the filling time of the pilot chute.

3) The snatch velocities, snatch force, main canopy filling time, opening force, and equilibrium characteristics are then calculated by the standard methods outlined earlier.

E. Results

The results of these calculations are presented in Table VIII.

TABLE VIII
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
G-12D CARGO PARACHUTE - A-22 CONTAINER

Release Altitude, $h = 6500$ ft								Landing Zone Elevation, $h_1 = 5000$ ft							
V_o (knots) (TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{D_t} (sec)	Ref. $t_{D_t}^{exp}$ (sec)	t_f (sec)	Ref. t_o^{exp} (sec)	t_o (sec)	Ref. $t_{T^{exp}}$ (sec)	t_T (sec)	Ref. $t_{T^{exp}}$ (sec)	t_s (sec)	Ref. F_s^{exp} (#)	F_s (#)	Ref. F_o^{exp} (#)	F_o (#)
60	95.3	30.9	2.76	4.13	6.89	55.43						6,822			3,447
90	140.8	30.9	2.31	2.79	5.10	55.64						10,110			7,477
120	185.2	30.9	2.06	2.13	4.19	52.73						13,332			12,999
150	228.7	30.9	1.88	1.73	3.61	52.15						16,464			19,700
Release Altitude, $h = 11,500$ ft								Landing Zone Elevation, $h_1 = 10,000$ ft							
60	96.0	33.4	2.80	4.05	6.85	51.76						6,523			3,285
90	142.1	33.4	2.36	2.74	5.10	50.01						9,795			7,194
120	187.3	33.4	2.09	2.08	4.17	49.08						12,135			12,499
150	231.5	33.4	1.93	1.67	3.60	48.51						15,986			19,394
Release Altitude, $h = 20,000$ ft								Landing Zone Elevation, $h_1 = 18,500$ ft							
60	97.0	38.4	2.98	3.95	6.93	45.99						6,130			3,125
90	144.1	38.4	2.45	2.65	5.10	44.16						9,135			6,895
120	190.4	38.4	2.18	2.00	4.18	43.24						12,119			12,031
150	235.8	38.4	2.01	1.62	3.63	42.69						15,047			18,450

X. G-11A CARGO PARACHUTE

The G-11A cargo parachute is normally used in conjunction with a load platform. The significant parameters of this parachute operation are listed below.

A. Physical Parameters

$D_o = 100 \text{ ft}$ - circular flat canopy

$W_b = 3500 \text{ lbs}$

$W_c = 133.7 \text{ lbs}$

$W_p = 193 \text{ lbs}$ (inc. wt. of risers - 38.64 lbs)

$(C_{DS})_b = 76.8 \text{ ft}^2$

Platform dimensions:

Length, $L = 8 \text{ ft}$
Width, $W = 8 \text{ ft}$

$C_{DP\text{platform}} = 1.20$ (Ref. 2)

$(C_{DS})_c = 12.25 \text{ ft}^2$ (deployment bag)

Bag dimensions:

Length, $L = 48 \text{ in}$
Width, $W = 35 \text{ in}$
Height, $H = 12 \text{ in}$

Canopy Material, nylon, 1.6 oz/yd^2 - MIL-C-7020
Type II Nominal Porosity = 70-176

$Z = 120$ suspension lines

$P' = 550 \text{ lbs}$ - Type III of Spec. MIL-C-5040

$L_s = 35 \text{ ft}$

$L_r = 20.5 \text{ ft}$

$L_w = 60 \text{ ft}$ webbing - Type XVIII of Spec. MIL-W-27265
Class R

$\xi' = 35\%$ at rated breaking strength

$\xi'_\text{riser} = 21\%$ at rated breaking strength

$$C_{D_0} = 0.75$$

$$K = 1.4$$

B. Deployment System

The platform load is extracted from the aircraft using a standard 15 ft diameter extraction parachute with a 260 in. reefing line. As the load exits the aircraft the extraction parachute force is transferred to the bridle of the G-11A assembly. The main canopy deployment bag is separated from the load, paying out the risers and suspension lines in a lines first deployment. When the canopy skirt leaves the bag, two reefing cutters are armed. The remainder of the canopy is extracted from the deployment bag breaking the tie that connects the apex of the canopy to the deployment bag. After a period of two seconds from cutter arming, the reefing line is severed in two places and the canopy continues its inflation process (Fig 9).

C. Assumptions Used in Calculations

1) The initial velocity, V_0 , is that of the cargo platform, and not necessarily the aircraft speed.

2) The release time, $t = 0$, is assumed to be when the platform leaves the aircraft ramp. The elapsed time for the extraction parachute opening sequence has been calculated in Section XI and can be included as an additive term prior to cargo exit from the aircraft. In addition to this, the time necessary for the cargo to traverse the distance inside the aircraft, under the influence of the extraction parachute drag, must be considered.

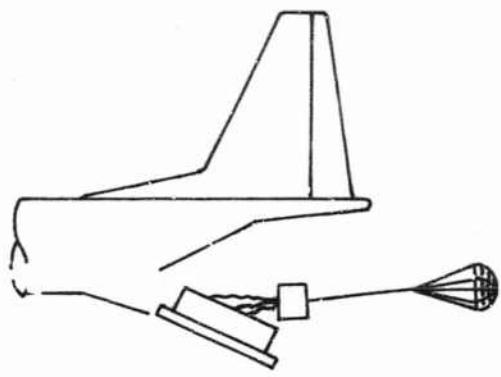
3) The deployment and opening sequence takes place in a near horizontal condition.

4) The filling procedure, for the period where the inlet of a reefed canopy grows from the reefed diameter to fully open, is identical to that of an unreefed parachute over the same filling period.

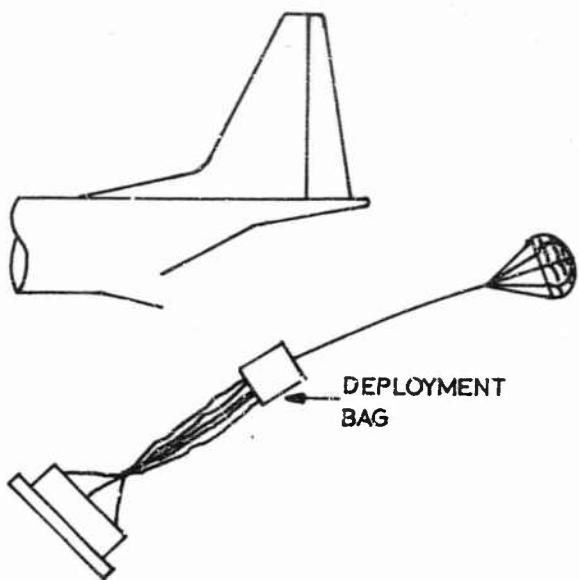
D. Governing Equations

1) The extraction time, until the platform crosses the aircraft ramp is given in Section XI. For this calculation, $t = 0$ occurs when the platform leaves the aircraft.

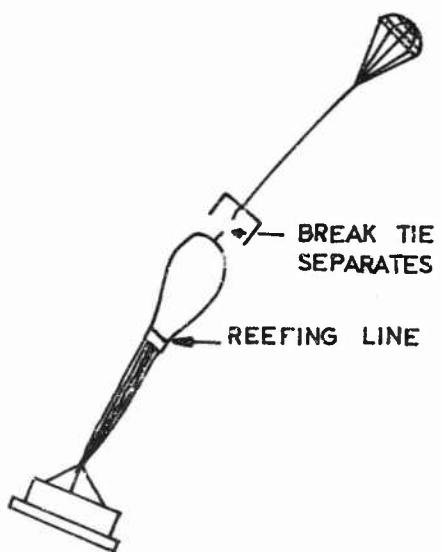
2) The suspension line extension time, t_2 , is given by Eqn 9, where the term L_s includes the riser line



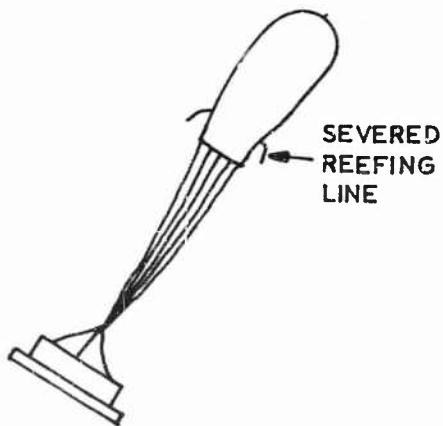
1. Deployment Initiated



2. Line Stretch



3. Main Canopy Reefed



4. Canopy Disreefed



5. Canopy Filled

Fig 9. G-11A Parachute Deployment Sequence

length and the term J_c contains drag area and mass terms of both the deployment bag and the extraction parachute in its fully inflated condition.

$$J_c = \frac{(C_D S)_c + (C_{D_0} S_0)_{ext}}{2(m_c + m_{ext})}$$

3) The velocity terms necessary for the snatch force calculations are determined from Eqns 10 through 13, assuming the deployment velocity term, V_d , equal to the initial platform velocity, V_0 , at exit from the aircraft.

4) The snatch force was then calculated from Eqns 14, 15, and 16.

5) The total filling time of the G-11A parachute system was determined by the following method.

First, the filling time of the unreefed G-11A canopy was obtained from the method of Ref 3, and a computer solution of Eqn 18. Then, the time elapsed while the inlet area increases from the reefed area ($S_1 = \pi D_r^2/4$) to fully open was determined by using an experimentally determined curve of instantaneous inlet area versus time for the unreefed canopy (Fig 10).

Assuming that the reefed and unreefed canopies have identical filling procedures during this period, the calculated value represents that portion of the filling time from disreef to fully open. Adding the two second reefing time yields the value for the total filling time. This method, then, assumes that the reefing cutters are armed at about the time of snatch force occurrence.

6) The opening force, F_o , was calculated from Eqn 4.

7) The rate of descent, V_e , was determined from the equilibrium condition (Eqn 6).

8) The total down time, t_T , has been calculated from Eqn 7, assuming equilibrium conditions exist during a fall of 1500 ft. However, the altitude loss during opening may be significant and the total time must be viewed with caution.

E. Results

The results of the performance calculations are presented in Table IX.

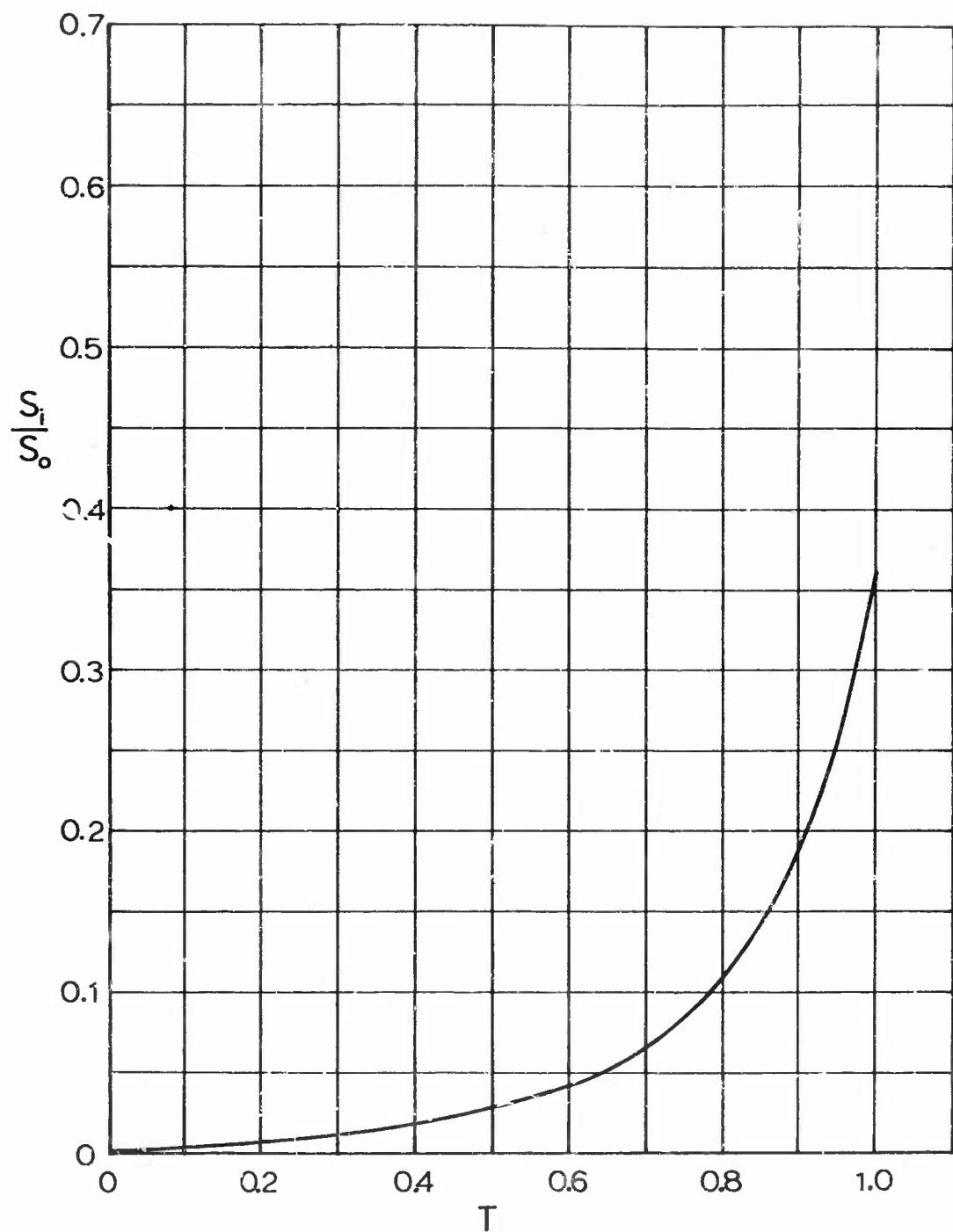


Fig 10. Ratio of Inlet Area to the Total Area as a Function of the Dimensionless Time, T

TABLE IX
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
G-11A CARGO PARACHUTE

Release Altitude, $h = 6,500$ ft							Landing Zone Elevation, $h_1 = 5,000$ ft						
V_o (knots/ TAS)	V_e (ft/ sec)	t_{Dt} (sec)	Ref. t_{Dexp} (sec)	t_f (sec)	Ref. t_{oexp} (sec)	t_o (sec)	Ref. t_{oexp} (sec)	t_T (sec)	Ref. t_{Texp} (sec)	F_B (#)	Ref. F_{sexp} (#)	F_o (#)	Ref. F_{oexp} (#)
60	29.8	25.0	1.94	9.16	11.10	71.10			6.829			2,866	
90	134.7	25.0	1.29	6.70	7.99	67.99			10.293			6,305	
120	179.5	25.0	0.97	5.40	6.37	66.37			13.760			9,639	
150	224.3	25.0	0.78	4.44	5.22	65.22			17.247			15,041	
Release Altitude, $h = 11,500$ ft							Landing Zone Elevation, $h_1 = 10,000$ ft						
60	90.9	27.0	2.02	8.78	10.80	66.36			6.729			3,252	
90	136.3	27.0	1.35	6.51	7.86	63.42			10.117			6,801	
120	181.8	27.0	1.01	5.25	6.26	61.82			13.512			11,184	
150	227.2	27.0	0.81	4.31	5.12	60.68			16.930			17,466	
Release Altitude, $h = 20,000$ ft							Landing Zone Elevation, $h_1 = 18,500$ ft						
60	92.7	31.1	2.18	8.33	10.51	58.74			6,464			3,138	
90	139.0	31.1	1.45	6.19	7.54	55.87			9,708			6,560	
120	185.3	31.1	1.09	4.95	6.24	54.27			12,972			11,118	
150	231.7	31.1	0.57	4.06	4.93	53.16			16,234			16,819	

XI. EXTRACTION PARACHUTES

Extraction parachutes are used to extract load platforms out of the cargo compartment of the aircraft. As a characteristic feature, it can be assumed that these parachutes are so small and inflate so rapidly that the velocity of the relatively heavy load does not vary during the period of parachute inflation. This condition is usually characterized as infinite mass condition.

Extraction parachutes of 15 ft, 22 ft, and 28 ft, nominal diameters, are under consideration. The 15 ft canopy is used both reefed and unreefed and the calculations have been performed for both cases.

A. Physical Parameters

- 1) 15 ft Ringslot parachute - unreefed

$$W_c = 6.06 \text{ lbs} \quad W_p = 8.06 \text{ lbs}$$

Canopy Material, nylon cloth MIL-C-7350 Type I,
2.25 oz/yd² Nominal Porosity = 90-165
ft³/ft²-min

$$(C_{DS})_c = 1.425 \text{ (deployment bag)}$$

Bag dimensions:

$$\begin{aligned} \text{Length, } L &= 18 \text{ in} \\ \text{Width, } W &= 10 \text{ in} \\ \text{Height, } H &= 3.5 \text{ in} \end{aligned}$$

$$C_{D_{bag}} = 1.14 \text{ (Ref 2)}$$

$$Z = 16 \text{ suspension lines}$$

$$P' = 1,000 \text{ lbs - Type IV of Spec. MIL-C-7515}$$

$$L_s = 15 \text{ ft}$$

$$L_{ex} = 60 \text{ ft}$$

$$\xi' = 20\% \text{ at rated breaking strength}$$

$$\xi'' = 28\% \text{ at rated breaking strength of 12,000 lbs}$$

$$\lambda_{total} = 17\%$$

$$C_{D_o} = 0.55$$

$$xK = 1.05 \text{ (infinite mass) (Ref 1)}$$

2) 15 ft Ringslot parachute - reefed

Unless note here, the parameters are those noted in 1) above.

Effective diameter, $D_{o_{eff}} = 12.0 \text{ ft}$

$L_r = 260 \text{ in}$

3) 22 ft Ringslot parachute

$W_c = 19.3 \text{ lbs} \quad W_p = 27.5 \text{ lbs}$

Canopy Material, nylon cloth, MIL-C-7350,
Type I, 2.25 oz/yd² Nominal Porosity =
 $90-165 \text{ ft}^3/\text{ft}^2\text{-min}$

$C_{D_{bag}} = 1.425$ (deployment bag)

Bag dimensions:

Length, $L = 18 \text{ in}$

Width, $W = 10 \text{ in}$

Height, $H = 3.5 \text{ in}$

$C_{D_{bag}} = 1.14$ (Ref 2)

$Z = 28$ suspension lines

$P' = 1500 \text{ lbs}$ - Type V of Spec. MIL-C-7515

$L_s = 22 \text{ ft}$

$L_{ex} = 60 \text{ ft}$ - 6 ply

$\xi' = 25\%$ at rated breaking strength

$\xi'' = 28\%$ at rated breaking strength of 40,000 lbs

Adapter Web length = 5 ft, 6 ply

$\lambda_{total} = 17\%$

$C_{D_o} = 0.57$

$xK = 1.05$ (Ref 1)

4) 28 ft Ringslot parachute

$W_c = 22.55 \text{ lbs} \quad W_p = 36.55 \text{ lbs}$

Canopy Material, nylon cloth, MIL-C-7350, Type I
2.25 oz/yd² Nominal Porosity = 90-165
 $\text{ft}^3/\text{ft}^2\text{-min}$

Bag dimensions:

Length, L = 23 in
Width, W = 14 in
Height, H = 10 in

$$C_{D_{bag}} = 1.14 \text{ (Ref 2)}$$

Z = 30 suspension lines

P' = 2,000 lbs - Type VI of Spec. MIL-C-7515

L_S = 28 ft

L_{ex} = 60 ft - 8 ply

ξ' = 30% at rated breaking strength

ξ'' = 28% at rated breaking strength of 52,000 lbs

Adapter Web length - 9.0 ft, 8 ply

λ_{total} = 17%

C_{D₀} = 0.55

xK = 1.05 (Ref 1)

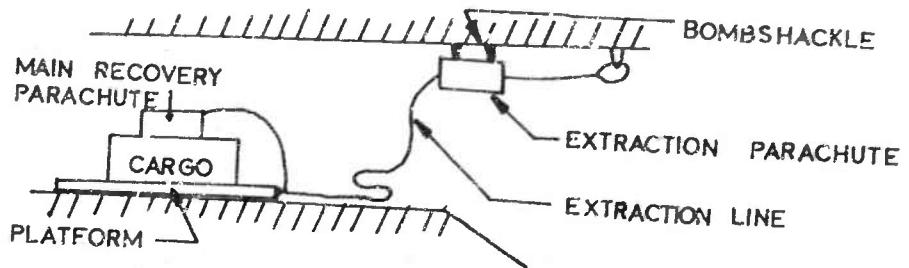
B. Deployment System

The extraction parachute assembly is supported in the rear of the cargo section on a bomb shackle. Upon release the deployment bag swings aft and is subjected to the air-stream behind the aircraft. The aerodynamic drag on the deployment bag extends the 60 ft extraction line to its full length at which time the canopy deploys, lines first, and inflates.

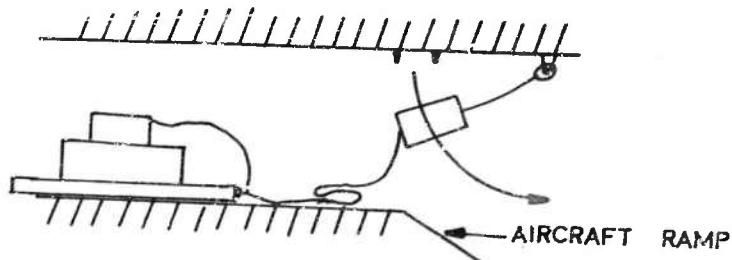
The payload in the aircraft is released at a predetermined extraction force and moves aft through the cargo compartment. As it passes over the exit ramp of the aircraft a mechanism transfers the extraction force from the cargo to the bridle of the main recovery canopy, and after this time, the extraction parachute functions much like a pilot parachute (Fig 11).

C. Assumptions Used in Calculations

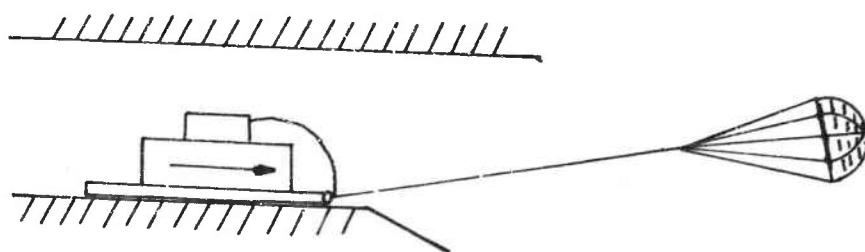
- 1) The deployment and opening sequence occurs in a near horizontal condition.



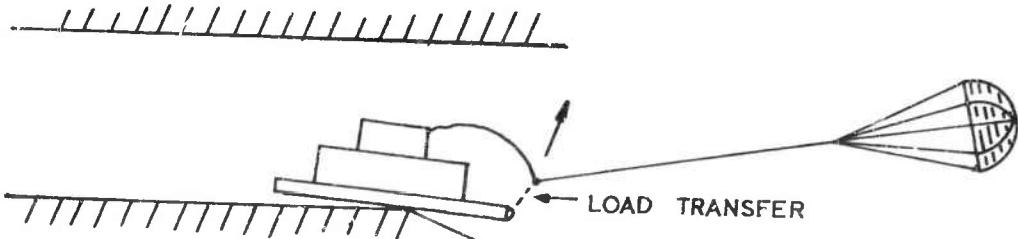
1. Aircraft Cargo Compartment



2. Bomb Shackle Releases Deployment Bag



3. Load Moves Through Cargo Compartment



4. Load Exits Aircraft and Extraction Force Initiates Deployment of Main Canopy

Fig 11. Extraction Parachute Deployment Sequence

2) The filling times and opening forces are calculated on the basis of infinite mass relationships.

D. Governing Equations

1) The time for extraction line extension is determined from Eqn 1 where:

$$L_1 = L_{ext} = 60 \text{ ft}$$

2) The deployment bag velocity at extraction line extension is given by

$$V_{II,1} = \frac{V_o}{J_c V_o t_1 + 1}$$

3) The time for suspension line extension, t_2 , is given in Eqn 9, where L_s includes the length of the adaptor web.

4) The velocity of the canopy at time t_2 is given by Eqn 11.

5) With this information, and realizing that the aircraft flies at a constant speed V_o , which in this case is $V_{I,2}$, the snatch force can be calculated from Eqns 14, 15 and 16.

6) The filling time for the infinite mass case is given by the equation

$$t_f = \frac{8 D_o}{V_s 0.9} \frac{\rho}{\rho_o} \quad (\text{Ref 4})$$

7) The opening force is calculated from Eqn 4 utilizing a constant infinite mass xK factor of 1.05.

8) The steady state rate of descent and velocity are not calculated for the extraction parachutes, since their functioning is essentially completed with the deployment of the main recovery parachute.

E. Results

The results of the performance calculations for the 15 ft, 22 ft, and 28 ft extraction parachutes are presented in Tables X through XIII.

TABLE X
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
15 FOOT RINGSLOT EXTRACTION PARACHUTE
UNREFINED

Release Altitude, $h = 6500$ ft							Landing Zone Elevation, $h_L = 5,000$ ft							
V_o (knots) (ft/ TAS)	V_3	V_e (ft/ sec)	t_{D_t}	Ref. $t_{D_{exp}}$	t_f	Ref. $t_{f_{exp}}$	t_o	Ref. $t_{o_{exp}}$	t_T	Ref. $t_{T_{exp}}$	F_S	Ref. $F_{S_{exp}}$	F_O	Ref. $F_{O_{exp}}$
60	101.3	2.48	1.55		4.53					2.268			1,027	
90	152.0	2.00	1.08		3.08					3,676			2,311	
120	202.7	1.60	0.83		2.43					5,025			4,108	
150	253.4	1.32	0.58		2.00					6,362			2,419	
Release Altitude, $h = 11,500$ ft							Landing Zone Elevation, $h_L = 10,000$ ft							
60	101.3	2.53	1.32		3.85					2,148			877	
90	152.0	2.06	0.92		2.98					3,505			1,974	
120	202.7	1.66	0.71		2.37					4,816			3,509	
150	253.4	1.37	0.59		1.95					6,097			5,483	
Release Altitude, $h = 20,000$ ft							Landing Zone Elevation, $h_L = 18,500$ ft							
60	101.3	2.61	1.00		3.61					1,916			663	
90	152.0	2.19	0.69		2.88					3,205			1,493	
120	202.7	1.79	0.54		2.33					4,444			2,654	
150	253.4	1.47	0.44		1.91					5,627			4,146	

TABLE XI
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
15 FOOT RINGSLOT EXTRACTION PARACHUTE
REEFED, $L_T = 260$ in.

Release Altitude, $h = 6500$ ft							Landing Zone Elevation, $h_1 = 5,000$ ft							
V_o (knots TAS)	V_s (ft/sec)	V_e (ft/sec)	t_{Dt} (sec)	Ref. t_{Dexp} (sec)	t_f (sec)	Ref. t_{fexp} (sec)	t_o (sec)	Ref. t_{oexp} (sec)	t_T (sec)	Ref. t_{Texp} (sec)	F_s	Ref. F_{sexp} (#)	F_O	Ref. F_{Oexp} (#)
60 101.3	2.48	1.34									2,265		657	
90 152.0	2.00	0.96									2,676		1,479	
120 202.7	1.60	0.66									N/A		5,025	
150 253.4	1.32	0.54									6,362		4,108	
Release Altitude, $h = 11,500$ ft							Landing Zone Elevation, $h_1 = 10,000$ ft							
60 101.3	2.53	1.06									2,148		561	
90 152.0	2.06	0.74									N/A		3,505	
120 202.7	1.66	0.57									4,016		2,246	
150 253.4	1.37	0.46									6,097		2,509	
Release Altitude, $h = 20,000$ ft							Landing Zone Elevation, $h_1 = 18,500$ ft							
60 101.3	2.61	0.50									N/A		1,916	424
90 152.0	2.19	0.55									N/A		2,205	956
120 202.7	1.70	0.43									4,444		1,590	
150 253.4	1.47	0.35									6,627		2,663	

TABLE XII
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
22 FOOT RINGSLOT EXTRACTION PARACHUTE

Release Altitude, $h = 6,500$ ft									Landing Zone Elevation, $h_1 = 5,000$ ft								
V_o (knots/ TAS)	V_s (ft/ sec)	V_e (ft/ sec)	t_{Dt} (sec)	Ref. t_{Dexp} (sec)	t_f (sec)	Ref. t_{fexp} (sec)	t_o (sec)	Ref. t_{oexp} (sec)	t_T (sec)	Ref. t_{Texp} (sec)	F_s (#)	Ref. F_{sexp} (#)	F_o (#)	Ref. F_{oexp} (#)			
60	101.3		2.98		2.27		5.25				2.507					2,209	
90	152.0		2.70		1.58		4.28		N/A		4,537					4,971	
120	202.7		2.36		1.22		3.58				6,594					8,838	
150	253.4		2.01		1.00		3.01				8,533					12,809	
Release Altitude, $h = 11,500$ ft									Landing Zone Elevation, $h_1 = 10,000$ ft								
60	101.3		3.01		1.94		4.95				2,277					1,887	
90	152.0		2.77		1.35		4.12		N/A		4,198					4,246	
120	202.7		2.44		1.04		3.48				6,158					7,548	
150	253.4		2.10		0.85		2.95				8,027					11,794	
Release Altitude, $h = 20,000$ ft									Landing Zone Elevation, $h_1 = 18,500$ ft								
60	101.3		3.04		1.47		4.51				1,887					1,427	
90	152.0		2.86		1.02		3.88		N/A		3,593					3,211	
120	202.7		2.58		0.79		3.37				5,393					5,708	
150	253.4		2.28		0.64		2.92				7 ± 69					8,920	

TABLE XIII
PARACHUTE PERFORMANCE CHARACTERISTICS OF THE
28 FOOT RINGSLOT EXTRACTION PARACHUTE

Release Altitude, h = 6,500 ft							Landing Zone Elevation, h ₁ = 5,000 ft							
V _o	V _s	V _e	t _{Dt}	Ref. t _{Dexp}	t _f	Ref. t _{fexp}	t _o	Ref. t _{oexp}	t _T	Ref. t _{Texp}	F _ε	Ref. F _{sexp}	F _o	Ref. F _{oexp}
(knots TAS)	(ft/sec)	(ft/sec)	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)	(sec)	(#)	(#)	(#)	(#)
60	101.3	3.06	2.89	5.95					4.224				3.579	
90	152.0	2.69	2.01	4.70	N/A				7.316				5.234	
120	202.7	2.29	1.55	3.84					10.371				14.315	
150	253.4	1.92	1.27	3.19					13.273				22.367	
Release Altitude, h = 11,500 ft							Landing Zone Elevation, h ₁ = 11,500 ft							
60	101.3	3.09	2.47	5.56					3.890				3.057	
90	152.0	2.76	1.72	4.48	N/A				6.861				6.877	
120	202.7	2.37	1.32	3.69					9.800				12.226	
150	253.4	2.00	1.08	3.08					12.599				19.104	
Release Altitude, h = 20,000 ft							Landing Zone Elevation, h ₁ = 20,000 ft							
60	101.3	3.14	1.87	5.01					3.315				2.312	
90	152.0	2.88	1.30	4.18	N/A				6.039				5.201	
120	202.7	2.52	1.00	3.52					8.789				9.246	
150	253.4	2.16	0.82	2.98					11.429				14.379	

XII. CONCLUSION

An attempt has been made to calculate the transient and steady state performance characteristics of a number of conventionally used man-carrying, cargo, and extraction parachutes. In view of the numerous assumptions, the predictions should be considered as approximations, based on currently available solutions.

It is recommended that this report be reviewed and revised as better analytical methods and experimental data become available.

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APPENDIX

GOVERNING EQUATIONS

This section presents the general equations used for the preceding calculations. In many cases in the main text these equations have been altered slightly for adaptability to a specific system. The altered equation number in the text is then shown with a lower case "a".

The equations shown in this Appendix are numbered as they appear in the main text, where an attempt has been made to maintain chronological order. However, since several systems have been considered, some deviations necessarily exist.

The governing equations for the extraction parachutes have been set down in Section XI, and since these canopies have identical deployment and filling characteristics, they have not been repeated in this Appendix.

1. Static line extension time, t_1 . (Ref 1)

This time was found by an iteration of the equation

$$L_1 = \left\{ \left(\frac{gt_1}{2} \right)^2 + \left[V_o t_1 - \frac{1}{J_1} \ln (1 + J_1 V_o t_1) \right]^2 \right\}^{\frac{1}{2}} \quad (1)$$

where

L_1 = length of static line

$J_1 = \rho (C_{DS})_b / 2m_{b+c}$

m_{b+c} = mass of suspended load plus complete parachute system

The velocity at this instant is given by:

$$V_d = V_{I,1} = \frac{V_o}{J_1 V_o t_1 + 1} \quad (2)$$

2. Pilot parachute filling time. (Ref 7)

If a pilot parachute is employed, it may be deployed by a spring action or static line. In either case, the filling time may be calculated using:

$$t_{fp} = \frac{2D_o}{3\pi V_o (9/70 - C/3)} \quad (8)$$

The opening force of the pilot parachute is very small compared to the main canopy force, and has not been calculated.

3. The suspension line extension time, t_2 . (Ref 1)

The time for suspension line extension is found from an iteration of the equation

$$L_s = \frac{1}{J_b} \ln(1 + J_b V_d t_2) - \frac{1}{J_c} \ln(1 + J_c V_d t_2) \quad (9)$$

where

$$J_b = \rho (c_{DS})_b / 2m_b$$

and

$$J_c = \rho (c_{DS})_c / 2m_c$$

4. The time, t_{Dt} , is the time from release to the instant which the deployment begins, t_1 , plus the time for suspension line extention, t_2 . Therefore, one may write

$$t_{Dt} = t_1 + t_2 . \quad (17)$$

If a pilot parachute is an integral part of the system, its pertinent times must be included in Eqn 17.

5. Component velocities. (Ref 1)

The velocities of the primary and secondary bodies, load and parachute, respectively, can be determined from:

$$V_{I,2} = \frac{V_d}{J_b V_d t_2 + 1} \quad (10)$$

$$V_{II,2} = \frac{V_d}{J_c V_d t_2 + 1} \quad (11)$$

$$V_{II,2(\text{rel})} = V_{I,2} - V_{II,2} \quad (12)$$

and

$$V_{I,3} = V_{II,3} = V_{I,2} = V_s \quad (13)$$

6. Snatch force calculations. (Ref 1)

The snatch force was calculated by the method of Ref 1, from which

$$F_s = P + F_c \quad (14)$$

where

$$F_c = \frac{\rho}{2} (C_{DS})_c \frac{V_{II,2}^2 + V_{II,3}^2}{2} \quad (15)$$

and

$$P = \sqrt{\frac{m_c [V_{II,2(\text{rel})}^2]}{L_s \xi}} \quad (16)$$

The various velocity parameters in the equations above were found in the preceding section.

7. Main canopy filling time, t_f . (Ref 3)

For canopies opening under finite mass conditions the filling time was determined from computer solutions of the following equations:

a) 10% flat extended skirt canopies.

$$D_o = t_f \int_{T=0}^{T=0.25} \frac{5.271T^2 + 2.597T + 0.2587}{\frac{M}{RV_s} + \frac{\rho t_f}{2} \left[\frac{S}{N} \left(\frac{M}{N} \ln \frac{M}{R} - T \right) + \frac{PT}{R} \right]} dT \quad (3)$$

where

M = sum of system and included air mass

$$= \frac{W_t}{g} + \rho D_o^3 (0.009169T + 0.00006475)$$

W_t = sum of parachute and suspended load weights.

N = rate of change of included air mass with respect to dimensionless time, $T = 0.009169\rho D_o^3$

P = sum of initial drag areas of vehicle and canopy = $0.00647 (C_{DS})_{\text{max}} + (C_{DS})_b$ where
 $(C_{DS})_{\text{max}}$ = maximum canopy drag area and
 $(C_{DS})_b$ = drag area of suspended load.

R = sum of initial masses of system and the included air =

$$\frac{W_t}{g} + 0.00006478 \rho D_o^3$$

S = rate of change of canopy drag area with respect to dimensionless time, $T = 0.1445 (C_{DS})_{max}$

b) Circular flat canopies.

$$D_o = t_f \int_{T=0}^{T=0.3} \left[\frac{\frac{1.87}{M} T^2 + 2.96T + 0.0886}{\frac{M}{RV_s} + \frac{\rho t_f}{2} \left\{ \frac{S}{N} \left(\frac{M}{N} \ln \frac{M}{R} - T \right) + \frac{PT}{F} \right\}} \right] dT \quad (18)$$

where

$$M = \frac{W_t}{g} + \rho D_o^3 (0.020624T + 0.0000264)$$

$$N = 0.020624 \rho D_o^3$$

$$P = 0.003733 (C_{DS})_{max} + (C_{DS})_b$$

$$R = \frac{W_t}{g} + 0.000264 \rho D_o^3$$

$$S = 0.12237 (C_{DS})_{max}$$

8. The opening time is, by definition of Ref 1, the time from the release to the time the canopy is fully inflated.

$$t_o = t_{Dt} + t_f \quad (5)$$

9. The maximum opening force for all the parachutes was calculated by the method of Ref 4 with

$$F_o = C_{D_o} S_o q_s x K \quad (4)$$

where

a) $C_{D_o} S_o$ is the drag area of the fully inflated canopy

b) $q_s = \frac{1}{2} \rho V_s^2$

c) K is a dimensionless factor

d) x denoted the relationship between actual opening shock F_o and the constant force F_c , $x = F_o/F_c$

10. The rate of descent, or the equilibrium velocity, for the parachutes was determined from force equilibrium expressed as

$$v_e = \frac{2}{D_o} \sqrt{\frac{2 W_{total}}{\pi C D_o (\rho_{ave})}} \quad (6)$$

where W_{total} is the sum of parachute weight and suspended load weight, and ρ_{ave} is the average density between parachute opening altitude and landing zone elevation.

11. The total down time, t_T , was determined from

$$t_T = t_o + \frac{1500}{v_e} \quad (7)$$

where the release altitude is 1500 ft above ground.

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